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Effects of Climate Change and Variability on Coffee Yield in Deder Woreda, Eastern Oromia, Ethiopia

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Research Article

Abstract

The agricultural sector is a pillar of the Ethiopian economy, but a range of factors including climate change and variability constrain the production of different crops including coffee in many parts of the country. The impact of climate change and variability on important cash crops has not been well assessed at the local scale. Therefore, the main objective of this study was to assess the effects of climate change and variability on coffee yield in Deder District. Historical climate and coffee yield for data 2004-2018-year intervals were obtained from the National Meteorological Agency (NMA) and Deder District Agricultural Office respectively. Rainfall and temperature parameters were characterized using Instat v.3.37. Pearson correlation revealed that belg rainy day ($r = 0.55$) had a positive strong correlation with coffee yield. belg rainfall total ($r = 0.49$) and kiremt rainy day ($r = 0.31$) had a positive moderate correlation with coffee yield. Kiremt rainfall total ($r = 0.11$), kiremt end date ($r = 0.11$), onset date of the belg rainy season ($r = 0.02$) and length of growing period ($r = 0.04$) had weak positive correlations with coffee yield. Moreover, belg mean temperature ($r = -0.3$) revealed a moderate negative correlation with coffee yield while kiremt mean temperature ($r = -0.16$) showed a weak negative correlation with coffee yield. The analysis of variance (ANOVA) showed the influence of climate variables on the yield of coffee are statistically significant ($p = 0.025$). Therefore, there is a need for more research on suitable coffee shade trees, exploring moisture stress and high-temperature resistant varieties, more attention to water conservation strategies, and moving coffee establishments at higher elevations.

Keywords: Climate change, variability, rainfall, temperature, coffee yield

1. Introduction

Climate change and variability have differential impacts across locations. The poor developing countries of Africa are among the most vulnerable to experience the worst of climate change

impacts. This is because the majority of the population depends on economic activities that are highly exposed and extremely sensitive to climatic variability, and national adaptive capacities are very low due to the high level of poverty, and unfavorable and deteriorating environmental conditions (Kihupi et al., 2015).
Ethiopia, one of the most populous countries in Africa, is vulnerable to climate change and variability due to its high dependence on rain-fed agriculture and relatively low adaptation capacity (Fikreyesus et al., 2014). The change and variability in climate patterns affect not only annual crops but also perennial cash crops, such as coffee and Cocoa (Craparo et al., 2015). These adverse climatic conditions directly affect each stage of coffee growth and consequently influence the yield and quality of coffee berries harvested (Camargo, 2010). Temperature above that which is required for the growth of coffee (19-25°C), for instance, hinders flowering and erratic rainfall hinders maturation of coffee berries, hence low production (Porter et al., 1999).
Besides, these climatic conditions also lead to spread and change in the distribution of pests and diseases such as Coffee Berry Disease (CBD) brought about by erratic rainfall, and movement of the coffee borer to higher altitudes due to global warming. In countries like Ethiopia, which heavily depend on rain-fed agriculture; both annual and perennial crop failure is almost unavoidable. Since climate variability is having a significant effect on coffee yield in Ethiopia, farmers are moving towards replacing coffee by "khat"(Adugna and Struik, 2011), especially in Hararghe. Given the portended changes in climate, rainfall and temperature may become more extreme and thus substantially impact coffee yield soon (Peuke et al., 2002).
Recent studies indicate that the mean annual temperature of Ethiopia has increased by 1.3 °C between 1960 and 2006, at an average rate of 0.28 °C per decade and by 0.3°C per decade in the south-west and Amhara in the north (Fazzini et al. 2015). Furthermore, there is a strong variability within Ethiopia's annual and decadal rainfall, which makes country-wide trends difficult to detect in the long-term. A study by Jury and Funk (2013) showed that February to May and June to September rains have declined 15–20% since the mid-1970s and late 2000s in southern, south-western, and southeastern Ethiopia. Similar to other parts of the country, Deder District has been experiencing drier growing periods leading to a reduction in coffee yield in terms of quality and quantity. However, the effects of these change and variability on the coffee yield is not well explored at the local level. Therefore, this study was aimed to analyze the effect of climate change and variability on coffee productivity in Deder District.

3.1 Materials and Method

2.1 Description of the Study Area
The study was carried out in Deder district, which is one of the major coffee-producing districts of East Hararghe administrative zone of Oromia Regional State. Geographically, Deder District is located between 9° 09'- 9° 24' N latitude and 41° 16'- 41° 32' E longitude. It is located 430 km from Addis Ababa, the capital city of Ethiopia. The district is bounded by Meta District to the east, West Hararge zone to the west, Malka Balo District to the south, and Goro Gutu District to the north.
The topography of the district is characterized by an undulated and rugged landscape with *Jamjemxeta* considered to be the highest point. Agro-climatically, the district encompasses highland (33%), midland (50%), and lowland (17%) with altitude ranging from 1200 to 3119 meters above sea level (masl) (Deder Agricultural and Natural office, 2018).
Annual average rainfall ranges from 600mm to 1500 mm. The district gets biannual rainfall, *belg* (short season, from the end of February to the middle of May), and *kiremt* (long season, from July to the end of September). The average precipitation is generally considered adequate for rain-fed agriculture. But uneven nature of its distribution especially in the lowland and midland

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parts of the district has resulted in frequent crop failure. The temperature of the area ranges from 11°C (min.) to 25°C (max.) (Deder *Woreda* Agricultural Office, 2018).

Cereals and cash crops are commonly grown in the district. Notable among the cereal crops are sorghum, maize, wheat, barley. *Khat*, coffee, and vegetables are the known cash crops. Cattle, goat, and sheep are among the livestock reared by the community. The district has an estimated total land area of about 67,428 ha of which 39 % is cultivable,3.8% forest and bushland, 3.4% residence and others, and the remaining 39.2% is considered rugged and mountains Deder *Woreda* Agricultural Office, 2018). The total population of the district is estimated to be over 242,108, of which 122,981 were male and 119,127 were female (Deder *Woreda* Agricultural Office, 2018).

2.2 Source of data

Fifteen years (2004-2018) coffee yield and rainfall and temperature data were obtained from the *woreda* Agriculture office (WAO) and the National Meteorological Agency (NMA) of Ethiopia.

2.3 Data analyses

2.3.1 Analysis of rainfall and temperature data

Rainfall and temperature data were rearranged in Microsoft excel sheet in days of the year format. Then, rainfall and temperature characteristics such as onset date of *belg* season and end date of *kiremt* rainy season, *belg* rainy days, *kiremt* rainy days, and length of growing period (*belg- kiremt*) were characterized using the built-in Instat statistical software version 3.37.

2.3.2 Correlation and regression analysis

Using observed rainfall and temperature and coffee yield data for a period of 2004-2018, the regression model was computed as follows: $Y=a+b1x1+b2x2+b3x3+b4x4+bnxn+e$ equation (4) Where Y = the value of the dependent variable (coffee yield in qt/ha), a = Y-intercept, $b1$, $b2$, $b3$, $b4$, … bn = regression coefficients (each b represents the amount of change in Y (yield) for one unit of change in the corresponding x-value when the other x values are held constant; $x1$, $x2$, $x3$, $x4$, ... xn = *belg* rainfall onset date, *kiremt* rain cessation date, length of the growing period, seasonal rainfall totals and number of rainy days, *belg* mean temperature and *kiremt* mean temperature, e = the error of estimate or residuals of the regression. Pearson Correlation coefficient (r) was used to see relationships between coffee yield with temperature and rainfall characteristics. Moreover, the coefficient of multiple determinations (R^2) was used to determine the percentage of coffee yield explained by rainfall and temperature together.

3.2 Results and discussions

3.3 Correlation Analysis of Rainfall Variables, Temperature and yield

As presented in Table 1, *belg* rainy day (r = 0.55) had a positive strong correlation with coffee yield. *belg* rainfall total (r = 0.49) and *kiremt* rainy day (r = 0.31) had positive moderate correlation with coffee yield. *Kiremt* rainfall total (r = 0.11), *kiremt end date* (r = 0.11), onset date of the *belg* rainy season (r = 0.02) and length of growing period (r = 0.04) had weak positive correlations with coffee yield. In general, all rainfall characteristics have indicated a positive correlation with coffee yield in the study area. Similarly, Jessica (2012) determined the insignificant but positive correlation between rainfall and coffee yield. He suggested that when there is a decrease in rainfall, yield of coffee also decreases. Another study also showed that drought is a major climatic limitation for coffee production (Damatta, and Ramalho, 2006).

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Additionally, *belg* mean temperature (r = -0.3) moderate negative correlation with coffee yield while *kiremt* mean temperature (r = -0.16) showed a weak negative correlation with coffee yield, which indicates a rise in both *belg* and *kiremt* temperature reduces coffee productivity in the study area during 2004-2018. The result of this study agrees with Davis et al. (2012), in which they showed that a growing success coffee plant is directly linked to accelerated climate change, but there is a profoundly negative trend in this relationship. As temperatures rise, *C. arabica* production will decrease. This will negatively impact Ethiopia's coffee industry. Similarly, Jaramillo et al. (2009) state that even the smallest increases in temperature could cause extensive damage to coffee production.

Table1.Pearson's lower triangular correlation matrix of rainfall and temperature characteristics and coffee yield

	Yield	BRD	KRD	BRT	KRT	BMT	KMT	Onset	LGP	End
Yield	1									
BRD	0.55	1								
KRD	0.31	0.65	1							
BRT	0.49	0.59	0.59	1						
KRT	0.11	0.08	0.07	0.26	1					
BMT	-0.3	0.05	-0.12	-0.15	0.42	1				
KMT	-0.16	-0.03	0.1	0.42	0.69	0.13	1			
Onset	0.02	-0.12	-0.26	-0.15	0.49	-0.08	0.17	1		
Lgp	0.04	0.27	0.47	0.48	-0.08	0.12	0.23	-0.85	1	
End	0.11	0.3	0.46	0.67	0.65	0.09	0.69	0.02	0.52	1

Note: BRD (*belg* rainy days), KRD (*kiremt* rainy days), BRT (*belg* rainfall total) KRT (*kiremt* rainfall total), BMT (*belg* mean temperature), KMT (*kiremt* mean temperature), Onset (onset date of *belg* rainy season), End (end date of *kiremt* rainy season), and LGP (length of growing period (*belg- kiremt*)).

3.4 Regression Analysis of Rainfall Variables, Temperature, and Yield

In order to quantify relationship that exists between coffee yield and rainfall characteristics, onset date of *belg* rainy season, end date of *kiremt* rainy season, length of growing period (*belg- kiremt*), *kiremt* season rainfall total and *kiremt* season rainy day, *belg* rainfall total and *belg season* rainy day, *belg* mean temperature and *kiremt* mean temperature were identified as explanatory variables and regressed against coffee yield.

Multiple regression analysis showed that the coefficient of multiple regressions (R^2) was 0.88 (i.e. 88% of the variation in coffee yield has been explained by the above mentioned climatic parameters jointly). The end date has been removed from the predictor position in the regression model because of the multicollinearity problem.

The analysis of variance (ANOVA) showed that the influence of climate variables on the yield of coffee are statistically significant (p = 0.025) (Table 2). According to the estimated model below, the variation in coffee yield (kg/ha) in Deder District was accounted variation, because of rainfall and temperature as follow; *belg* rainy days (4.23Kg/ha), *kiremt* rainy days (-0.76 kg/ha), = *belg* rainfall total (0.29Kg/ha).), x4 = *kiremt* rainfall total (0.75Kg/ha), x5 = *Belg* mean temperature (-174Kg/ha), x6 = *Kiremt* mean temperature (178.13Kg/ha), x7= onset date of rain (-4.31Kg/ha) x8= Length of growing period (-2.7Kg/ha)

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Table2.Summary of regression values for predictors

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Sig.
	0.94	0.88	0.723	0.53	0.025

Y = 6841.7+4.23x1-0.76x2+0.29x3+0.75x4-174x5-178.13x6-4.31x7-2.7x8
Where, Y = predictable coffee yield (kg/ha), x1 = *belg* rainy days (days), x2 = *kiremt* rainy days (days), x3 = *belg* rainfall total (mm).), x4= *kiremt* rainfall total (mm), x5 = *Belg* mean temperature (°C), x6 = *Kiremt* mean temperature (°C), x7= onset date of rain (DOY) x8 = Length of growing period (DOY).

Table3.Coefficients of regression analyses for the effect of rainfall and temperature characteristics on coffee yield

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Intercept	6841.7	13.19	-	5.19	0.002
BRD	4.23	0.006	-0.457	1.91	0.105
KRD	-0.76	0.006	-0.072	-1.21	0.27
BRT	0.29	0.001	0.064	2.13	0.04
KRT	0.75	0.002	0.329	4.23	0.01
BMT	-173.98	0.456	0.414	-3.82	0.01
KMT	-178.13	0.563	0.162	-3.17	0.02
Onset	-4.31	0.013	0.059	-2.78	0.03
Lgp	-2.7	0.013	0.282	-2.16	0.07

3.5 Summary and Conclusions

This study was undertaken in Deder *woreda* to determine the effect of rainfall and temperature on yield of coffee. Fifteen years (2004-2018) coffee yield and rainfall and temperature data were obtained from the *woreda* Agriculture office (WAO) and the National Meteorological Agency (NMA) of Ethiopia.

In the context of the above-mentioned objective, the study analyzed the following rainfall and temperature characteristics such as; onset date of *belg* season and end date of *kiremt* rainy season, *belg* rainy days, *kiremt* rainy days and length of growing period (*belg*- *kiremt*), *belg* mean temperature and *kirem*t mean temperature for 2004-2018 interval were characterized using the Instat statistical software version 3.37. Pearson Correlation coefficient (r) was used to see relationships between coffee yield with temperature and rainfall characteristics. Moreover, the coefficient of multiple determinations (R^2) was used to determine the percentage of coffee yield explained by rainfall and temperature together.

belg rainy day (r = 0.55) had a positive strong correlation with coffee yield. *belg* rainfall total (r = 0.49) and *kiremt* rainy day (r = 0.31) had a positive moderate correlation with coffee yield. *Kiremt* rainfall total (r = 0.11), *kiremt end date* (r = 0.11), onset date of the *belg* rainy season (r = 0.02) and length of growing period (r = 0.04) had weak positive correlations with coffee yield. In general, all rainfall characteristics have indicated a positive correlation with coffee yield in the study area.

Moreover, *belg* mean temperature (r = -0.03) and *kiremt* mean temperature (r = -0.16) had showed a negative strong correlation with coffee yield. This indicated a rise in *belg and kiremt* temperature cause a reduction in coffee yield in the study area. Multiple regression analysis showed that the coefficient of multiple regressions (R^2) was 0.88 (i.e. 88% of the variation in coffee yield has been explained by the above-mentioned rainfall and temperature together).

Conflicts of Interest: The authors declare no conflict of interest.

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